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Smart Manufacturing and Digital Integration of Steel Processing Operations in Saudi Arabia under Vision 2030: Linking ERP, Production Planning, Cost Control, and Value-Added Fabrication

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Abstract

Saudi Arabia's industrial diversification agenda places increasing importance on converting steel inputs into traceable, commercially competitive products. Yet digital investment in steel processing frequently addresses isolated machines or administrative functions rather than the connections between order acceptance, material allocation, production execution and financial control. This integrative review examines how enterprise resource planning (ERP), production planning, manufacturing execution, process analytics and job costing can operate as a coherent management system for downstream steel processors. Thirty peer-reviewed works published between 2021 and 2025 were critically assessed across organisational integration, scheduling, steel-specific optimisation, digital twins, sustainability and manufacturing economics. Evidence indicates that digital value depends on disciplined material identification, interoperable transactions and decisions that reconcile physical yield with customer service and realised margins. The synthesis develops an order-to-margin integration framework distinguishing the commercial, planning, execution, assurance and financial layers, together with observable indicators and implementation gates. Particular attention is given to coil slitting, cut-to-length processing, tube manufacture and structural fabrication, where product variety, remnant management and variable machine utilisation make conventional aggregate reporting inadequate. The review argues that Saudi processors can strengthen local value addition by adopting modular integration around verifiable production events rather than pursuing automation as an end in itself. It identifies critical trade-offs involving planning stability, data ownership, cyber-risk and workforce capability, and outlines a testable agenda for multi-site research. The contribution is a contextualised analytical synthesis, not a claim of measured performance gains within Saudi factories.

Keywords: Steel processing; manufacturing execution; ERP integration; finite scheduling; cost control; value-added fabrication; Saudi Vision 2030

1 Introduction

Steel is often discussed through capacity, furnace technology and commodity prices. These perspectives matter, but they say relatively little about how a purchased coil or plate becomes a profitable fabricated item. In downstream operations, value is created through matching grades and dimensions to demand, sequencing shared equipment, containing scrap, demonstrating conformity and delivering reliably. A plant may possess modern machinery yet struggle to connect the quotation issued to a customer with the consumption, rework and labour recorded against the finished order. Digital transformation therefore requires attention to transaction integrity as well as equipment intelligence.

Recent scholarship increasingly locates manufacturing transformation within organisational design, data integration and operational decision rights rather than technology procurement alone. Organisa-

tional reviews distinguish firm strategy, factory processes, information, people and supply-chain relationships [1], while research on industrial digitalisation warns against treating technological adoption as evidence of realised benefit [2]. Reviews of intelligent execution systems similarly show that capturing equipment signals is different from converting them into coordinated decisions [3]. These insights are particularly consequential for manufacturers selling relatively low-margin, specification-sensitive steel products under variable demand.

Saudi Vision 2030 provides the strategic setting, but the industrial question is more specific than whether factories should become digital. Local processors must identify which digital capabilities would support efficient conversion of semi-finished inputs into tubes, profiles, cut sheets and assembled structures. Imported material, volatile order mixes, demanding engineering documentation and fragmented commercial systems create risks of expensive inventory with limited traceability. A defensible transformation strategy should therefore connect factory-level improvements with measurable manufacturing value added, rather than assume every additional dashboard generates productivity.

The available literature offers extensive work on enterprise systems, digital twins, scheduling algorithms and environmental outcomes. However, these streams are seldom assembled around the economic unit that matters to a downstream processor: an individual order linked to specific material batches, production routes and realised costs. This paper addresses that fragmentation by evaluating how information travels from customer requirements to engineering, planning, machines, inspection, dispatch and the financial ledger. It does not claim that the same technical architecture will suit every mill, service centre or fabrication workshop.

2 Aim, objectives and review questions

The aim is to construct a critically grounded operating framework for integrating commercial, manufacturing and cost information in Saudi downstream steel processing. Unlike studies concerned primarily with overall technology readiness, this review takes the material transformation route and its corresponding financial record as the central analytical objects.

Four objectives structure the inquiry: to identify the transaction boundaries at which steel-processing information is lost or duplicated; to evaluate how integrated planning can accommodate product variety, remnants and equipment constraints; to specify a cost and performance logic linking physical production events with financial outcomes; and to assess the organisational conditions required for adoption under Saudi industrial-development priorities. The review addresses two questions. First, which connections between ERP, scheduling, execution and costing are necessary for trustworthy order-level decisions? Secondly, under what circumstances does further automation improve the economics, adaptability and accountability of value-added fabrication?

The proposed contribution is an explanatory framework and an evaluation agenda rather than an operational optimisation algorithm. Accordingly, the argument distinguishes established findings from reasoned extensions to particular Saudi production settings. The distinction is important because transferring a result from an integrated steelworks to a mixed-order tube and fabrication business requires explicit attention to different routings, volumes and commercial constraints.

3 Materials and methods

An integrative, evidence-led review design was selected because the research problem crosses operations management, manufacturing information systems, optimisation, accounting and industrial sustainability. A narrowly quantitative comparison would be misleading: the selected studies use different units of analysis, from survey responses and conceptual architectures to case-study production lines and mathematical experiments. The review instead evaluates explanatory mechanisms, operational transferability and unresolved contradictions across disciplines.

The search was undertaken in October 2026 using publisher records, institutional research repositories, indexed scholarly summaries and bibliographies. Combinations of the terms steel processing, smart manufacturing, ERP, manufacturing execution, production planning, coil cutting, digital twin, material traceability, activity-based costing, circularity and Saudi Arabia were applied. Eligible works were peer-reviewed studies published from 2021 through 2025, available with identifiable bibliographic metadata and a DOI, and directly informative about one or more links in the proposed production-management chain. The final analytical corpus comprises 30 papers. This is a purposefully selected critical sample; it is not presented as an exhaustive database census, and no unverifiable search or screening totals are asserted.

Each work was examined against a common extraction scheme: industrial setting, technology or organisational intervention, decision affected, performance construct, empirical basis and implementation limitation. The analysis proceeded through three interpretive passes. First, studies were assigned to thematic families without assuming that claims from one production context generalise automatically. Secondly, points of convergence and disagreement were compared, particularly over centralised planning versus local responsiveness and analytical sophistication versus operational data quality. Thirdly, the findings were translated into transaction interfaces and control responsibilities for representative downstream steel operations. Table 1 summarises the resulting evidence map.

Validity in this form of review rests on transparency and analytical restraint, not statistical representativeness. Each bibliographic DOI was checked against an identifiable publication record. The proposed framework and indicators are authorial syntheses of reviewed findings, not observations made at a named Saudi plant. Vendor implementation claims, unverified improvement percentages and unsupported national market estimates were excluded. Transferability is discussed through explicit assumptions about machine heterogeneity, customer specifications and resource availability; future empirical testing remains necessary.

The evidence strands and their transfer limitations are summarised in Table 1.

Table 1. Evidence strands, operational interpretation and transfer limitations.

Evidence domain	Studies	Implication for steel processors	Principal limitation
Organisational and ERP integration	[1–6]	Defined masters, interfaces and transaction owners	Heterogeneous legacy machines and adoption costs
Planning and steel cutting	[7–12]	Finite capacity; coil pattern and remnant-aware scheduling	Optima depend on demand mix and practical restrictions
Execution, twins and quality	[13–17]	Batch genealogy, deviation detection and coded rework	Models require verified events and periodic recalibration

Evidence domain	Studies	Implication for steel processors	Principal limitation
Environment and material loops	[18–22]	Route-normalised energy and reusable material tracking	Avoid attribution based on unadjusted aggregates
Security, economic and Saudi context	[23–30]	Risk controls, cost-to-serve and staged local pilots	Causality and transfer across sites remain unsettled

4 Evidence synthesis: From systems to production decisions

4.1 Enterprise architecture and transactional discipline

ERP structures the commercial and accounting vocabulary of a factory: item masters, suppliers, inventories, customer orders, bills of materials, routing assumptions and general-ledger postings. Its strength is consistency across departments, not second-by-second process control. Reviews of ERP-guided transformation in smaller firms emphasise managerial sponsorship, process design and staged implementation rather than reliance on software features [5]. Industrial information integration research likewise identifies inconsistent data capture and process definitions as persistent sources of interoperability failure [6]. Consequently, the boundary between the accounting record and the physical item deserves careful design.

For a downstream steel order, the shared identifier should relate the sales line to the engineering revision, allocated coil or plate, production traveller, inspection result and dispatch package. Material identity requires more than a stock-keeping code: grade, heat or batch, thickness, coating condition, certificate and actual available dimensions can determine whether stock is substitutable. If a remnant is returned to inventory without its usable width, weight and certification status, ERP may report a valuable asset that production cannot employ. Conversely, undocumented consumption can make an otherwise efficient job appear unprofitable.

Manufacturing execution systems bridge these records with time-stamped events on the shop floor. A review of intelligent execution systems separates acquisition, analysis and decision support [3]; six industrial cases show that legacy equipment and interface constraints remain major obstacles to end-to-end connectivity [4]. The managerial implication is that integration must define ownership of each event. ERP authorises and values material; planning reserves resources; execution confirms actual quantities and stoppages; quality releases conforming output; finance reconciles variances. Sending every sensor measurement into ERP would increase noise without improving accountability.

4.2 Production planning under mixed-order constraints

Classical production plans aggregate capacity and demand, whereas steel service centres confront discontinuous choices about coil allocation, cutting patterns, shared tools and delivery priorities. Literature on smart scheduling shows that real-time visibility is useful only when scheduling rules remain intelligible and capable of responding to disruption [7]. Comparative reviews identify hybrid planning as a practical response to uncertain manufacturing environments, although no universal solution dominates [8]. Morphological assessment further reveals many unresolved combinations of scheduling objectives, computational approaches and shop-floor conditions [9].

Consider a slitting line receiving orders for different strip widths and minimum delivered weights. A nominally efficient pattern can generate remnants whose future usability is doubtful, while a pattern with slightly more immediate trim waste may release urgent orders and improve service performance. Optimisation research in steelmaking demonstrates the relevance of practical operational con-

straints [10]. More directly, steel coil slitting research reports how heterogeneous stock, leftover reuse and customer fulfilment interact in a real industrial case [11]. These studies support treating material allocation and production sequence as coupled choices, not independent steps performed by different departments.

The scheduling objective should therefore expose its trade-offs. Possible terms include customer lateness, setup time, lost yield, avoidable handling, overtime, remnant carrying cost and machine-specific quality restrictions. Management must select weighting rules rather than conceal them inside a proprietary score. Orders with stringent certification or surface requirements may be ineligible for an otherwise attractive stock substitution. Automated process-planning reviews stress the need to connect routing feasibility with rescheduling after disturbances [12]. A reliable system should also explain why a recommended plan changed, preserving a decision log for commercial and production review.

For tube mills and structural fabrication, additional constraints arise from changeovers in roll tooling, welding availability, dimensional tolerances, fabrication drawings, batch heat treatment and inspection hold points. The planning hierarchy may therefore separate a weekly capacity commitment, a daily finite schedule and an event-triggered recovery plan. Replanning at every new sensor event would destabilise crews and material movements. Instead, thresholds should determine when a disruption is sufficiently consequential to warrant intervention. This distinction between information freshness and decision frequency is central to workable digital integration.

4.3 Material yield, fabrication and quality feedback

Steel processing produces a genealogy of transformed material. A parent coil can be divided into daughter coils, cut sheets, tubes or profiles, which may later become welded assemblies. Commercial traceability must follow this many-to-many relationship rather than rely on the fiction that one order corresponds to one raw-material batch. Manufacturing execution should capture input identity, machine, operator or automated cell, route step, good output, rework and scrap disposition. Measurement points need to match production physics: metres and mass are not interchangeable without dimensions and density assumptions.

Steel-specific digital-twin research illustrates how linked upstream and downstream process information can improve the analysis of cold-rolling quality [13]. Broader studies find benefits in dynamic process representation, but caution that models depend on data consistency and maintenance [14, 15]. Work on steel materials and machine learning highlights the importance of chemistry, processing history and service requirements [16]. These insights imply a hierarchy of controls: first establish trustworthy material events, then detect deviations, and only subsequently deploy predictive models. A sophisticated quality algorithm cannot repair an incorrectly identified batch.

In fabrication, inspection outcomes must also reach quoting and planning. Repeated weld repair may indicate inaccurate cycle-time standards, unsuitable joint design or training needs; recurring edge defects may reveal a tooling or incoming-material issue. Digital-twin-assisted metal forming shows how prediction can support process adjustment [17], but models developed for controlled settings should not be treated as general proof that all fabricated steel processes can be predicted precisely. Effective feedback turns a non-conformance into a coded cause, a revised standard and a documented corrective action, rather than leaving it as an isolated quality record.

4.4 Cost control as an operational measurement system

Traditional standard costing often converts material, labour and overhead into average rates. Such averages are defensible for routine financial reporting but can obscure differences between small bespoke orders, high-volume repeat production and jobs requiring multiple changeovers. An integrated model should distinguish quoted, planned, actual and reconciled cost. Quoted cost represents the commercial assumption; planned cost reflects the feasible route and material allocation; actual cost reflects time-stamped consumption; reconciled cost closes discrepancies after returns, quality decisions and dispatch.

Material cost must recognise usable remnants, recoverable scrap and inventory valuation policy without double counting. A gross-yield calculation divides accepted output mass by issued input mass, whereas an economic-yield measure also accounts for the realizable value and probability of reusing leftovers. These measures answer different questions. A plant can improve apparent yield by classifying unusable fragments as stock, while worsening its true cash conversion. Similarly, absorbing unplanned rework into normal overhead may protect reported job margins but conceal a recurring production problem.

Time attribution also requires discipline. Run time, setup, planned maintenance, breakdown, queueing and material shortage should not be collapsed into one utilisation percentage. Activity-based costing informed by digital records offers a useful route to estimating service-specific resource consumption; recent manufacturing research also explores combining such costing with simulation [29]. However, data granularity creates administrative costs of its own. A practical rule is to capture a cost driver only when its variation materially influences pricing, scheduling, process improvement or financial reconciliation.

The decisive link is between operational events and management response. When slitting produces an unexpectedly large remnant, the cost system should not simply report negative variance. It should distinguish commercial underpricing, poor cut-pattern selection, constrained stock choice and execution loss. Those causes imply different interventions: a quoting change, a planning rule, a purchasing decision or maintenance. The resulting dashboard should report contribution by order and product family alongside on-time delivery, quality, inventory ageing and cash tied up in remnants. Cost control then becomes a learning mechanism rather than retrospective blame.

4.5 Environmental and circular performance

Digital manufacturing and sustainability can reinforce one another, but their relationship is conditional. A steel-focused dynamic life-cycle assessment demonstrates the importance of time-sensitive process assumptions [18], while research on digital platforms within steel supply chains shows how fragmented information can obstruct closed material loops [19]. A multi-perspective review of steel energy efficiency likewise describes the need to connect evaluation, diagnosis and process improvement [20]. These findings favour resource indicators that are traceable to defined operations rather than broad claims of decarbonisation.

For downstream processing, meaningful measures include electricity per accepted tonne for comparable product routes, unrecovered trim loss, reusable remnant conversion and avoidable transport between facilities. An apparent energy improvement may merely reflect a shift toward simpler products; a higher recovery rate may be achieved by creating low-quality inventory. Environmental interpretation must therefore normalise for mix and consider end-of-life material quality. Digitisation

can make these trade-offs visible, but it does not remove them [22]. Studies linking circularity with digital tools further stress inter-organisational coordination rather than software alone [21].

4.6 Commercial decisions and the cost of complexity

Integration also changes the information available before an order is accepted. A conventional quotation can apply an average conversion rate to purchased tonnes, then add a margin percentage. Such a method treats two orders with identical mass as economically comparable, even where one requires unusual tooling, separate inspection, frequent handling or significant offcut generation. A more informative quotation distinguishes material commitment, route-specific conversion costs, capacity opportunity cost and customer-specific service obligations.

An important distinction concerns average machine utilisation and profitable throughput. A production manager might maximise running hours by processing readily available material, yet displace orders with higher contribution or tighter contractual penalties. Conversely, preserving capacity for uncertain urgent work imposes a real economic cost. The integrated system should permit explicit scenario comparisons rather than allowing throughput to stand in for profitability. Flexible planning is particularly valuable when commercial priorities change after material has been reserved, because reallocation can create handling, inventory and scheduling consequences that are otherwise invisible.

Investment assessment should likewise distinguish infrastructure from application benefits. Connecting an older machine may require additional sensing, network segmentation and operator terminals before a single forecasting model can function. A credible business case therefore includes integration maintenance, staff learning, master-data remediation and process redesign as well as hardware. It should compare an achievable pilot against an existing manual baseline and specify when the new system will be retired or redesigned if operational evidence does not support its cost. These disciplines protect firms from equating large capital projects with strategic modernisation.

5 Proposed integrated operating framework

The synthesis proposes an order-to-margin architecture with five connected decision layers. At the commercial layer, a validated customer requirement creates a quotation and order baseline containing technical revision, delivery promise and target contribution. At the planning layer, material availability, cutting options, routing and finite capacity generate a feasible commitment. The execution layer records actual input, output, labour, machine state and interruptions. An assurance layer binds certificates, inspections and concession decisions to the product genealogy. Finally, the financial layer prices consumption, reconciles recovery and closes the contribution margin. Figure 1 depicts these relationships as a controlled information loop rather than a one-way software pipeline.

The proposed architecture is shown in Figure 1.

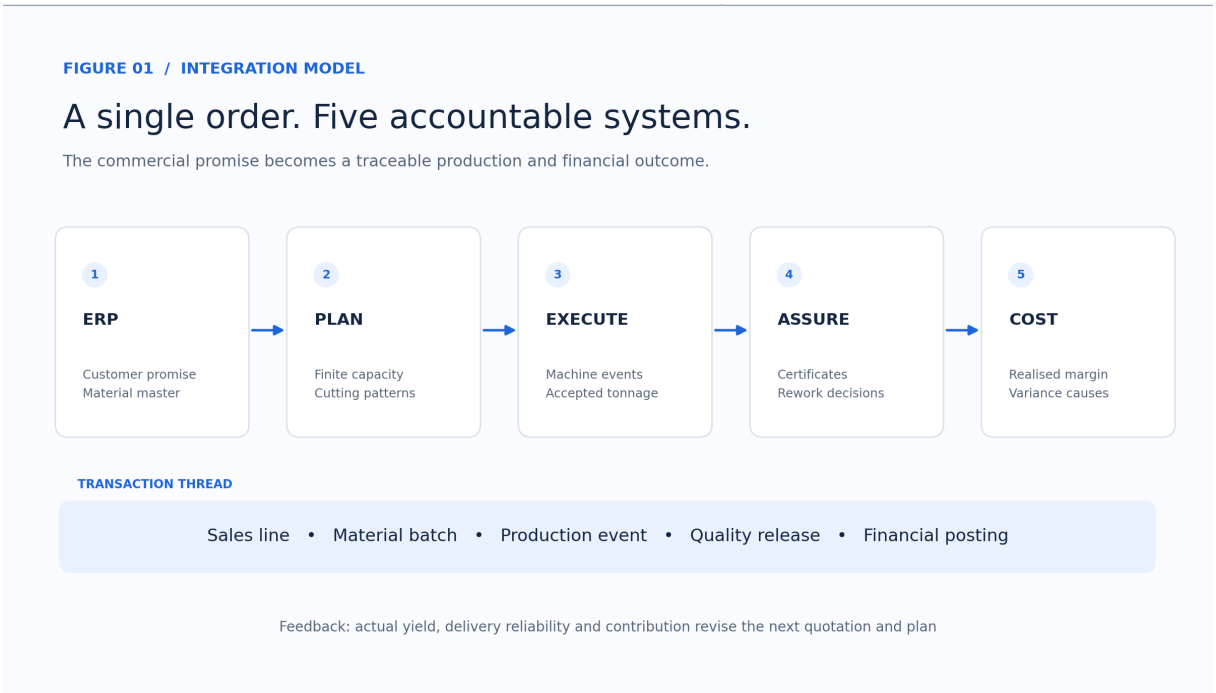


Figure 1. Proposed order-to-margin information architecture; conceptual synthesis of the reviewed evidence.

The integrating mechanism is a small set of governed transactions. Material issue, operation start, accepted quantity, scrap disposition, quality release and dispatch confirmation should be machine-readable, timestamped and linked to the same order lineage. Each event requires a responsible system and exception procedure. If the physical quantity differs from ERP stock, an authorised reconciliation should preserve the original event rather than overwrite it. If an engineering revision changes material requirements after allocation, the system should display the stock and cost consequences before rescheduling.

Figure 2 translates this logic into the life of a steel order and shows where decisions can be corrected. The first intervention point is quotation: technical complexity must be priced using a credible route. The second is allocation: stock alternatives are assessed against constraints and remnant value. The third is dispatch to production: a frozen schedule protects stable execution. The fourth is inspection: acceptance or rework changes available-to-promise quantities. The fifth is settlement: actual consumption informs subsequent pricing. Together these interventions form a closed learning cycle without suggesting that software should override qualified production judgement.

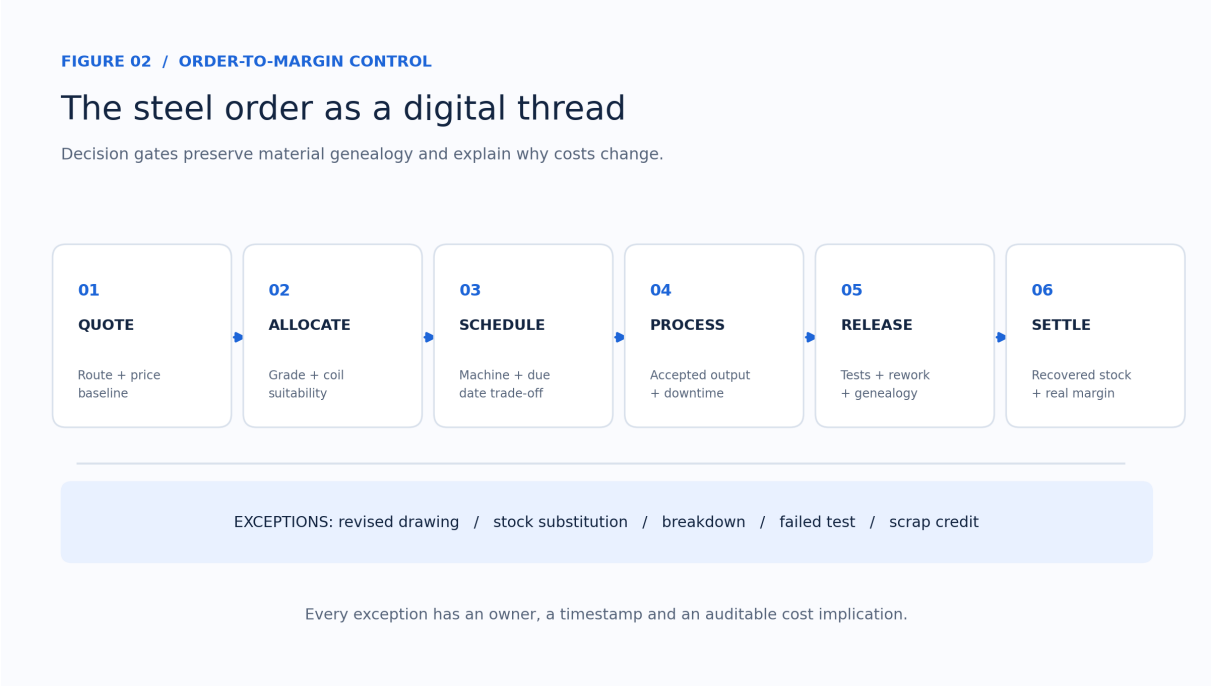


Figure 2. The downstream steel order thread and the principal exception-control gates.

The framework also distinguishes digital maturity from digital expenditure. Level one establishes disciplined item and material masters. Level two creates electronic production confirmations and genealogy. Level three connects finite scheduling with costed variances. Level four introduces condition monitoring and predictive support where validated data justify it. Progression should depend on evidence that prior controls work reliably. More advanced analytics before reliable transaction records risks producing elegant representations of an inaccurate factory.

5.1 Measurement definitions and decision ownership

Table 2 proposes a concise control register for operational evaluation. Each measure requires a precise numerator, denominator, responsible owner and treatment of exceptions. Accepted-output yield should not rise merely because work awaiting inspection has been temporarily counted as good production. Likewise, on-time delivery should distinguish the original customer commitment from a date renegotiated after delay. The record should preserve both, permitting fair review of responsiveness without rewriting history.

Cost indicators need similarly explicit boundaries. Order contribution should identify the point at which material recovery credits are recognised and whether disputed rework is borne by production, warranty or a supplier. Inventory ageing should separate reusable certified remnants from quarantined, obsolete or unidentified stock. Without such definitions, plants can report apparent improvements generated by classification changes rather than better execution.

Measurement must also lead to action. A monthly performance review can group exceptions by controllable cause, route and customer segment, then decide whether to amend pricing assumptions, stock policy, scheduling constraints or work instructions. Managers should record the intervention and check its subsequent effect against an appropriate comparison group. Where outcomes are affected by order mix or seasonal demand, raw before-and-after averages may be misleading. The purpose of digital measurement is disciplined learning, not the production of ever more indicators.

Table 2. Proposed evaluation indicators and their accountable owners.

Indicator	Operational definition	Owner	Interpretive safeguard
Accepted material yield	Accepted output mass ÷ issued input mass	Production / quality	Segment by route; quarantine excluded
Remnant conversion	Remnant mass reused ÷ certified reusable remnant mass	Stores / planning	Age and feasible future width matter
Original-date fulfilment	Orders delivered by original promise ÷ due orders	Commercial	Retain any revised commitment separately
Changeover burden	Recorded setup hours ÷ completed route batches	Operations	Compare like tooling and product families
Order contribution	Net realised revenue − attributable conversion and material costs	Finance	Document scrap credits and rework allocation
Traceability completeness	Released outputs with validated parent material link ÷ all released outputs	Quality / IT	Investigate broken genealogy before analytics
Energy intensity	Metered electricity ÷ accepted tonnes within route	Engineering	Normalise for grade, thickness and utilisation

6 Saudi Arabian application: Feasibility and governance

The domestic policy setting creates a case for integrating downstream production as part of industrial localisation. Nevertheless, national ambition does not establish the profitability of any individual investment. Saudi manufacturers operate across different maturity levels, customer sectors and order volumes. An empirical study of smart-factory adoption points to relationships among production integration, manufacturing performance and sustainability, while also considering the role of public support [27]. Comparative research involving Saudi and UK manufacturers identifies differences in digital and circular capabilities, suggesting that adoption pathways require local adaptation rather than direct transplantation [30].

A practical starting point for a Saudi service centre is an operational baseline covering three months of orders across representative product families. Managers should document how quotations are made, where stock identities change, how shortages are escalated, what triggers rework and how finished tonnes enter the ledger. A limited pilot could then connect one cutting line and one fabrication route to ERP using standardised identifiers and controlled interfaces. The pilot should include complex orders as well as routine jobs; otherwise the reported gains will not test the sources of actual planning difficulty.

Governance has at least four dimensions. Commercial and production managers must jointly authorise priority rules. Engineering and quality teams must control specification revisions and product release. Finance must agree how remnants, scrap and rework are valued. Information technology and operational engineering must protect system availability and industrial data. Research on manufacturing cybersecurity emphasises risks from manipulated production information [23], while analysis of converged operational and information networks shows why security architecture cannot be added after deployment [24]. Access segregation, audited changes, offline recovery and operator training are therefore requirements of operational reliability, not peripheral compliance tasks.

Workforce development is equally important. Operators require usable interfaces and a clear explanation of why new confirmations matter; planners need confidence to interrogate algorithms;

accountants need to understand process yield rather than only ledger totals. Firm-level evidence suggests digital practices interact with organisational barriers and capability [25], while industrial carbon-performance studies caution against assuming uniform outcomes across types of enterprise [26]. The Saudi opportunity lies in combining technical integration with the development of process engineering and analytical judgement inside local firms.

6.1 Implementation safeguards and scale-up criteria

A pilot should have written entry and exit criteria. Entry requires named process owners, a complete material dictionary, tested backup procedures and a representative selection of product routes. During the pilot, production teams should validate electronic events against physical counts and original job records. Discrepancies should be logged by cause, not silently repaired in spreadsheets. Exit requires evidence that traceability and reconciliation are dependable, that dispatch performance is not impaired and that the cost of maintaining interfaces remains acceptable.

Scale-up should follow operational learning. For example, adding computer-assisted cutting optimisation is justified after the plant can reliably distinguish useful remnants from nominal scrap. Predictive maintenance becomes more credible when stoppage codes and asset histories are consistently recorded. Cross-site dashboards become meaningful only after comparable measures and engineering definitions have been adopted. These dependencies create a practical sequence of management decisions while preserving flexibility for different plants to advance at different rates.

7 Discussion, limitations and research agenda

The central finding is that smart manufacturing has a relational, not merely technological, character. ERP becomes more useful when linked to trustworthy shop-floor events; scheduling becomes more credible when its capacity and material assumptions are visible; and cost control becomes actionable when variances retain their operational causes. The combined benefit is not simply faster reporting. It is the capacity to make and revise commitments using consistent evidence, while retaining accountability for the trade-offs chosen.

Three tensions qualify this argument. First, standardisation improves data exchange yet risks overlooking exceptions in grades, tooling and customer specifications. Second, centralised optimisation can improve resource use but may weaken local responsiveness when disturbances are frequent. Third, increasing data detail can reveal losses while imposing recording burdens and cyber-exposure. Studies of the organisational implementation of advanced manufacturing and sustainable planning similarly emphasise contingencies rather than universal prescriptions [1, 28]. The proposed architecture therefore favours common identifiers and decision principles with configurable, documented local rules.

The available evidence is also uneven. Algorithms tested on large integrated production lines may outperform manual practice under their study assumptions, but transfer to smaller service centres depends on inventory variety, software quality and production culture. Digital-twin research contains persuasive demonstrations yet remains exposed to interoperability and model-maintenance problems [15]. Survey research can associate adoption with performance but cannot, without stronger designs, isolate the impact of an ERP-to-costing interface. Accordingly, this review proposes no fabricated productivity percentage, payback interval or national emissions saving.

Future studies should use longitudinal, matched operational data from multiple Saudi steel processors. An appropriate design would compare baseline and post-integration order cohorts while adjusting for product mix, grade, order size, downtime and seasonality. Primary outcomes should include accepted-tonne yield, remnant reuse, delivery reliability, rework cost, inventory days and order contribution; secondary outcomes might address electricity intensity and operator workload. Analysis should separately test the contributions of master-data integrity, scheduling sophistication and predictive models. Interviews could explain why mathematically attractive schedules are rejected or why accurate records are not used in decisions.

The conceptual model also invites falsification. It would be weakened if reliable order genealogy failed to improve variance diagnosis, if cost transparency systematically reduced delivery performance, or if benefits were concentrated only in stable high-volume lines. Such outcomes would identify the limits of transaction-centred integration and inform differentiated strategies for tube mills, flat-product processors and bespoke fabrication. This is a more useful research agenda than treating every digital initiative as successful by definition.

8 Conclusion

Downstream steel competitiveness depends on coordinating commercial commitments, physical transformations and financial accountability. This review brings together thirty recent studies to show why ERP, finite planning, manufacturing execution, quality traceability and cost control should be designed as one decision system. Its principal contribution is an order-to-margin framework that connects identifiable production events with material genealogy, managerial intervention and credible economic measures. The framework is especially relevant where mixed orders, reusable remnants and inspection-intensive fabrication complicate average cost and utilisation figures.

For Saudi Arabia, the implication is selective, measurable integration aligned with local value addition under Vision 2030. Management should establish reliable master data and production events before investing in more elaborate optimisation or predictive tools. Adoption decisions must also address workforce capability, cybersecurity, material valuation and the limits of cross-factory comparisons. The framework requires empirical testing in Saudi plants; until that evidence exists, its value lies in specifying what integration should do, how results should be measured and which assumptions should be challenged.

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